National Aeronautics and Space Administration

Heritage and Advanced Technology Systems Engineering Lessons Learned from NASA Space Missions

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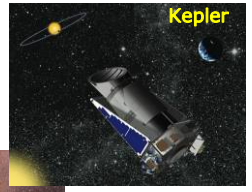
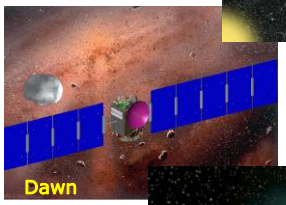
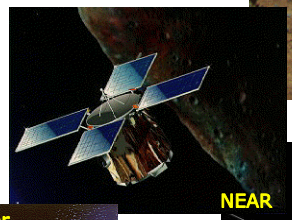
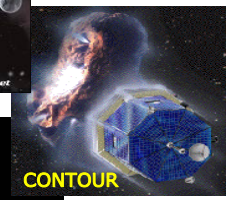
Discovery & New Frontiers Programs (D&NF) Science Missions

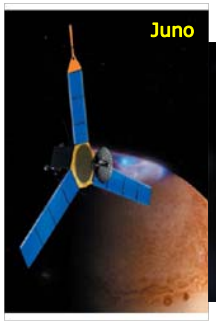
- The Moon (Lunar Prospector, M^3, GRAIL)
- Mars (Mars Pathfinder, ASPERA-3)
- Inner Planets (MESSENGER, Strofio)
- **Outer Planets (New Horizons, Juno)**
- Comets (CONTOUR, Stardust, Deep Impact, EPOXI, NExT)
- Asteroids (NEAR, Dawn)
- Interplanetary Space (Genesis)
- **Extra-Solar System (Kepler)**

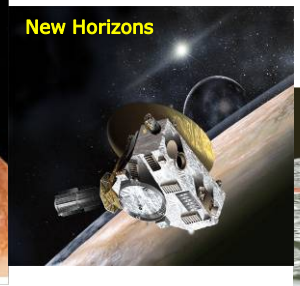


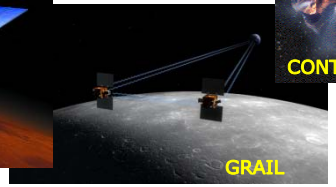










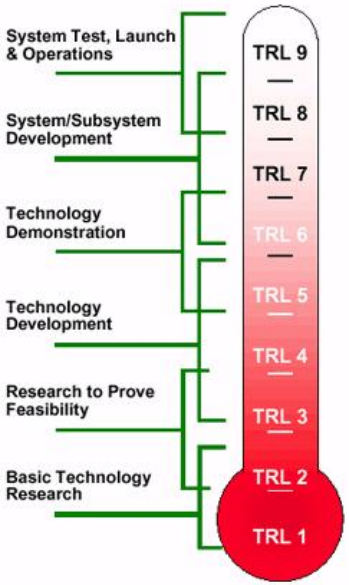


Definitions

Heritage Systems: Hardware, software, and procedures with previous flight history that are reused for a new mission in order to enable a mission capability or reduce overall mission cost, schedule, or risk.

Inheritance: The process of evaluating the compatibility and benefits of heritage systems to the requirements of a new project, and validating the level of reuse or rework (design, fabrication or coding, process or procedure development, documentation) required to use the heritage system in the new mission environment. Often called the “heritage process”.

Technology Readiness Level: A measure of the maturity of new technologies and the likelihood of its success when used operationally o achieve mission success.



The phrase “Heritage” is often used loosely to describe the holistic process, but systems engineering should be aware of difference between heritage and inheritance.

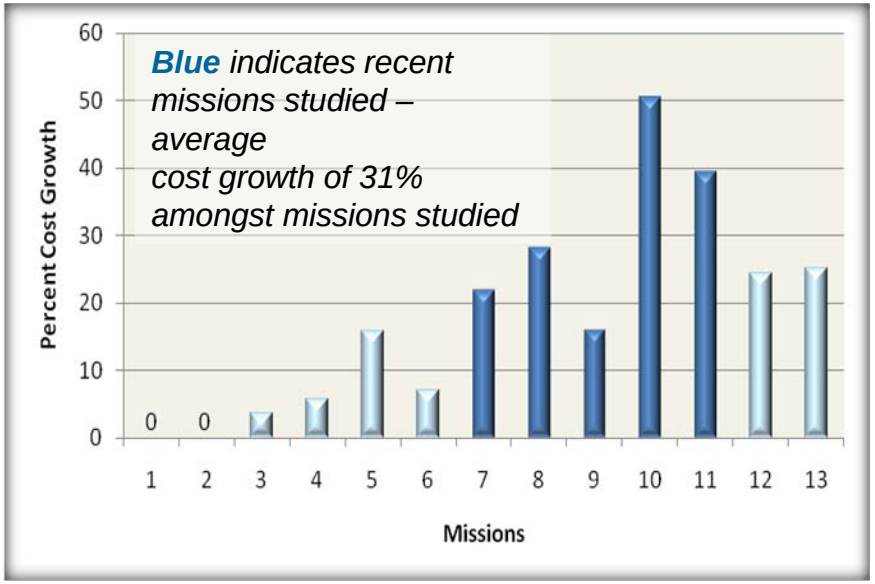
Heritage and New Technology in D&NF Missions

In the D&NF missions studied, four of the five experienced cost and schedule growth traceable to issues involving use of heritage and advanced technology

Study also indicated that cost growth could be traced to problems that were embedded as a result of decisions made during formulation

D&NF missions are small cost-capped, competed missions to fly frequently and acquire science

- Missions use heritage to reduce cost and risk; cost and risk reductions are rarely fully realized
- Missions incorporate new technology to enable science;
  new technology costs more than expected
- Resulting cost growth affects program futures and ability to meet program requirements



Insufficient Concept Development/Validation

Inadequate consideration of changes to the spacecraft configuration and the operational environments of the heritage technology compared to the mission being proposed

- Environment includes the spacecraft systems environment and the mission environment
  - Thermal: temperatures higher than operational constraints or component generates excessive heat for nearby components
  - Radiation: additional rad hardening or shielding in deep space environment
  - Other issues, such as loads, power, data rates, time delays, expected life time, etc.
- Use of multiple heritage technologies for a single mission, rather than threat of single component issues, burdens team with continuous stream of multiple changes to overall mission system design

Issues increase the overall time and cost for design and redesign

Identification of significant changes late in the formulation process (phase B or early phase C) may not allow adequate time for long lead procurements identified as mitigations

Assumptions Based on Unproven Heritage

Projects claim heritage for technology that has not flown or has not operated for its planned lifetime

- Reduction in development costs or schedule are not realized when in-flight anomalies require analysis support or redesign, or when in-flight performance is not as expected
  - Incomplete validation of instrument use at science target and mission environment
  - Late identification of requirements or design issues
  - Project support to investigation teams and root cause identification
  - Recommend operational workarounds to mitigate the risk of anomalies
  - Interchange or regression test engineering and flight units during spacecraft integration and test

Underestimation of Implementation Effort

Projects still tend to be overly optimistic about the effort that will be required to incorporate heritage technology or qualify new technology

- Changes to heritage system require revalidation and qualification for the planned operational environment and life time of new mission
- Qualification of new technology required to meet the mission science requirements
  - Design or manufacturing changes
  - Complete, up-to-date documentation
  - Multiple new technologies in a single mission
  - Assumption of synergies with other missions in development
  - Availability of expert personnel
  - Decreased level of required insight or oversight for heritage technology
  - Integration/qualification of “cutting-edge” technology coupled with typical spacecraft development issues
- Requires allocation of current project resources to support failure analyses, understand implications to current mission, and develop mitigation strategies or perform trade studies

Potential Causes

Primary cost growth drivers were not typically technical issues, but involved inheritance approach for heritage or new technology systems

- Drivers imbedded during mission formulation; realized during Integration and Test (I&T) phases
- Primary growth drivers could have been analyzed, understood, and estimated earlier in the development life cycle

Potential causes

- Each new mission is unique – science goals, environment, operations
- Proposal and concept study funding and time are limited
- Project management and SE selection processes concentrate on proving the cost savings and risk reduction due to heritage, not questioning or evaluating inheritance assumptions and claims of reduction
- Perception that cost increases late in the development life cycle are “safe”

Practical Mitigations for Systems Engineering

Ensure the time and resources are available to perform critical analyses during mission formulation phases

Identify key heritage and new technology risks

- Emphasize risk identification and prioritization, mitigation strategies, and tracking schemes
- Define threats against project reserves and reassess regularly

Formulation phase analyses should consider

- Differences between the previous (heritage technology) or tested (new technology) and planned spacecraft and operational environments
- Actual in-flight experience: has the technology been flown for the full planned mission
- Realistic synergy with parallel development efforts
- Availability of expert personnel as needed by the formulation and development schedule
- Careful tailoring of engineering processes and insight/oversight for inherited technology
- Changes in manufacturers, manufacturing processes, and materials

Conclusion

Use of heritage and new technology is necessary/enabling to implementing small, low cost missions, yet overruns decrease the ability to sustain future mission flight rates

The majority of the cost growth drivers seen in the D&NF study were embedded early during formulation phase and later realized during the development and I&T phases

Cost drivers can be avoided or significantly decreased by project management and SE emphasis on early identification of risks and realistic analyses

SE processes that emphasize an assessment of technology within the mission system to identify technical issues in the design or operational use of the technology

- Realistic assessment of new and heritage spacecraft technology assumptions , identification of risks and mitigation strategies
- Realistic estimates of effort required to inherit existing or qualify new technology, identification of risks to estimates and develop mitigation strategies
- Allocation of project reserves for risk-based mitigation strategies of each individual area of heritage or new technology
- Careful tailoring of inheritance processes to ensure due diligence

The Discovery and New Frontiers Program Office Life Cycle Cost Study was performed under the direction of Paul Gilbert (MSFC), led by Bryan Barley (MSFC), and supported by Kenny Mitchell (MSFC-retired) and Marilyn Newhouse (CSC)

Supplemental Data and Backup